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Extraction II - Local orbit bumps, extracted beam phase space and an intital look at fast resonant extraction.

Summary

In this report we give details of a system of local orbit control across the extraction septa using conventional bump magnets located in "warm" sections of the lattice. The conventional nature of these magnets allow this system to be used for both fast and slow resonant extraction. We then make some remarks on the phase space area of the extracted beam and conclude with an intital look at a layout for fast resonant extraction which appears to have good extraction properties.

Local Orbit Bumps

In an analogous fashion to the main ring, control of resonant extraction requires local orbit bumps capable of providing independant control of the horizontal radial offset and angle at both the electrostatic and magnetic septa. This local orbit control is accomplished by using pairs (or groups of three) of bump magnets located at suitable places in the lattice. The pulsed nature of fast resonant extraction provides the additional constraint that at least some (if not all) of the bump mangets be of a conventional nature located in "warm" sections of the Tevatron i.e., mini-straight or long straight sections. Slow orbit bumps can be made using the

superconducting correction dipoles located in the quadrupole correction coil package. The usefulness of these "cold" bumps is restricted somewhat by the small amount of bending power (96 kG-in) available. When calculating the effects of various bump magnets we shall use a Tevatron lattice which includes the high beta straight sections (see UPC report 14) with the extraction septa located at the upstream end of these long straight sections.

To start with we shall consider the effect of the correction coil dipoles at the same position in the lattice as the existing POS and ANG main ring bumps i.e., F46-A17 and F44-A15. The equations relating a kick at one point in the lattice to a change in position and angle at another point are

$$\Delta x_2 = (\beta_1 \beta_2)^{1/2} \sin \Delta\psi \Delta x'_1 \quad (1)$$

$$\Delta x'_2 = \left(\frac{\beta_1}{\beta_2} \right)^{1/2} (\cos \Delta\psi - \alpha_2 \sin \Delta\psi) \Delta x'_1 \quad (2)$$

where α, β are the lattice parameters at the positions in question

$$\Delta\psi = \psi_2 - \psi_1 \text{ the relative phase change.}$$

For an extraction septum at the upstream end of a high beta long straight section then $\alpha \approx 3.0$ $\beta \approx 225$ ms.

At 1000 GeV a 96 kG-in dipole will produce an angular deflection of a 73 μ rad, which gives at the septum:

1) POS type bump

$$\Delta x = 11 \text{ mms} \quad \Delta_x' = 150 \text{ } \mu\text{rad}$$

II) ANG type bump

$$\Delta x = 5 \text{ mms} \quad \Delta_x' = -110 \text{ } \mu\text{rad}$$

The large angular change in the POS bump is due to the fact that the high beta straight section has a large value of α at the septum position which enhances the sin term in equation 2; this effect is somewhat undesirable as changes in position (or angle) would be accompanied by correspondingly large changes in angle (or position). Assuming that bipolar power supplies will be used on the correction coil dipoles then linear combinations of the two local orbit bumps can be made in such a way as to give position (or angle) changes without changing the angle (or position). The maximum positional change achievable in this way is 13 mms, the maximum angular change 180 μ rad. We shall now turn to conventional bump magnets.

Of necessity the possible lattice locations for warm elements is restricted which in turn means that the orbit bumps must be made using three dipoles not two. One advantage of using convention dipoles is that more bending strength is available than from the correction coil dipoles. More specifically in this report we shall use 40" dipoles capable of producing a maximum field of 15 kG which gives a maximum bend angle of 460 μ rad at 1000 GeV. As before we shall consider a POS type bump and an ANG type bump. The POS dipole triplet consists of magnets located at the 48 mini-straight section, the center of the long straight section and the downstream end of the long straight section. The ANG triplet consists of magnets at the upstream end, center, and downstream end of the long

straight section.

Tables 1 and 2 give the results obtained for both the POS and ANG type local orbit bumps across a high beta straight section. From these results it is apparent that the POS bump is now essentially a pure position and the ANG bump a pure angle, a much cleaner situation than that obtained with the superconducting bump. The conventional nature of the magnets also means that any local orbit steering needed for fast resonant extraction could also be made using these magnets. It is for these reasons that we prefer the conventional magnet solution to the problem of providing local orbit steering around the extraction septa.

TABLE 1 - POSITIONAL LOCAL ORBIT BUMP

Position in lattice	Δx mm's	Δx μ rad	Magnet kick μ rad
A48 mini straight section	0	0	250
Extraction septa	11.25	9	-
Center of long straight section	11.5	9	-460
Downstream long straight section	0	-451	451

TABLE 2 - ANGULAR LOCAL ORBIT BUMP

Upstream long straight section	0	0	200
Extraction septa	0.2	200	-400
Downstream long straight section	0	-200	200

Extracted Beam Phase Space

During the slow resonant extraction process the position of the fixed points (and hence the separatrix) does not stay constant as the stable phase space area shrinks to zero. The inherent momentum dispersion of the circulating beam will also smear the fixed point positions. It is therefore important to know exactly how much movement to expect from the separatrix during the extraction cycle. The method used to calculate this effect is relatively straight forward. We take the two extreme cases in terms of stable phase space area (zero phase space, $.04\pi$ mm-mrad stable phase space) we then fold in the extreme values of momentum dispersion ($\Delta p/p = \pm .025\%$) and plot the separatrices for the two worst cases from the four available combinations of phase space and momentum offset. These two extreme examples will then define the emittance of the slow extracted beam.

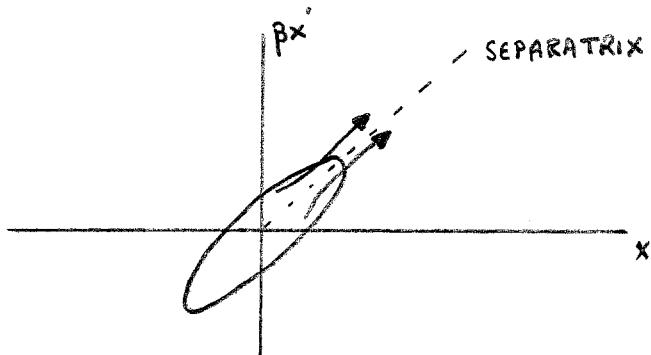
Figures 1 through 4 show the extreme separatrices for both 1/2 and 1/3 integer extraction. Figures 5 and 6 are composites of 1 and 2, 3 and 4. The resultant phase space area is .12 mm-mrad for 1/3 integer and .07 mm-mrad for the 1/2 integer case. These results are similar to the current main ring values and as such should not provide any major problems in the switchyard.

Fast Resonant Extraction

We shall present here the initial results we have obtained on fast extraction. The design goal we are attempting to achieve is to realize the capability to extract all the circulating beam in \sim 1ms. We have not yet performed the detailed calculations on the time structure of the extracted beam presented in this section, but based upon experience with the main ring we can say that the results we have obtained so far are consistent with this design criteria.

The actual mechanics of fast resonant extraction are somewhat different from slow resonant extraction i.e. fast extraction is not just slow extraction speeded up. During the slow resonant extraction process (1/2 integer say) the circulating beam is gradually brought into the unstable 1/2 integer machine resonance causing the stable phase space area of the beam to gradually shrink to zero with the unstable beam being "squeezed" out along the separatrices in a well controlled fashion. In fast resonant extraction, on the other hand, the slow extraction quadrupoles bring the beam close to (but not into) resonance, and then fast pulsed quadrupoles are used to drive all of the beam into an unstable condition at the same time. It is the duration

and strength of these pulsed quads which determines how much beam is extracted and on what sort of time scale. The idea of fixed points defining a stable phase space region not valid as the whole of the beam is now unstable. It is still valid however, to define a separatrix in phase space which will represent an "average" trajectory:

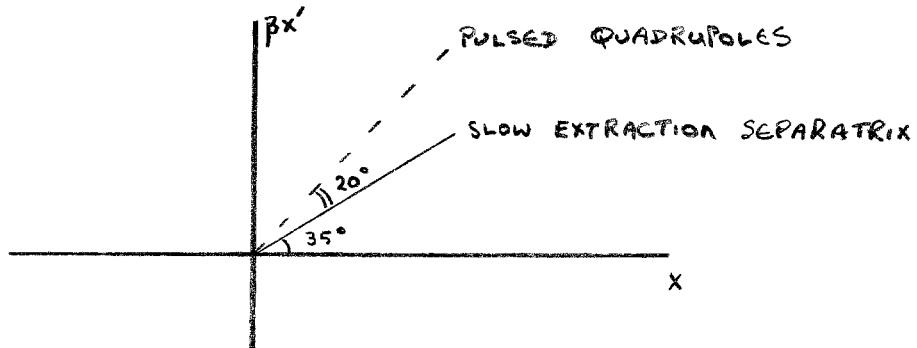


Individual particles at different places in the phase space ellipse will follow different trajectories as indicated above, with the particles closest to the center of the ellipse lying closest to the separatrix. For the purposes of this report we shall only investigate the behavior of the separatrix (the more detailed analysis will be given later).

Another feature of fast resonant extraction is that the phase space trajectory of the separatrix changes with the pulsed quadrupole strength. The pulsed quads can be thought of as applying a rotation of the separatrix trajectory. Thus a half sinewave quadrupole pulse will rotate the separatrix clockwise on the rising edge of the pulse and then anticlockwise back to the original phase angle on the following edge. It is conceivable that this phase angle change could be as large as 20° . (It is possible that this effect could be responsible for the higher

extraction losses experienced in multi-pulsed extraction from the main ring). One final point to note in regards to fast resonant extraction is that the effective extraction quadrupole strength is much higher than in the slow extraction case, which gives a correspondingly larger turn-to-turn step size change which in turn will change ratio of step size across the septum to septum radial offset.

The fast pulsed nature of the required extraction quadrupoles precludes the use of superconducting elements, which restricts the location of these elements to "warm" sections of the machine. A quick look at the Tevatron lattice shows that the mini-straight sections at the 48 locations are the only places in the lattice which have the relative phases close to the required values. Pulsed quadrupoles at these locations are actually $\sim 20^\circ$ different in phase from the slow extraction elements i.e.



Intuitively this $\sim 20^\circ$ phase angle mismatch between the slow extraction quadrupoles, which are used to bring the beam close to resonance, and the pulsed quadrupoles might be expected to cause problems. In actual fact the opposite is true. As the pulsed quadrupoles are fired the resultant phase angle attempts to increase from 35° towards 55° , at the same time the quadrupole

induced phase angle rotation is attempting to force it in the other direction. The relative magnitude of these effects is similar and in the first order approximation will cancel. In theory then we have just described a fast resonant extraction system which may work better than the existing main ring.

Figure 7 shows the phase space separatrix trajectory for slow 1/2 integer resonant extraction. Figures 8 through 10 show the same thing for fast resonant extraction for three different values of pulsed quadrupole field strength (with an electrostatic septum at a 14 mm offset). It is apparent that there is very little rotation of the separatrix trajectory. The data in the lower left of the plots is a list of the extraction elements, their position in the lattice and their relative strengths. The field gradients of the pulsed quadrupoles is given explicitly in Gauss/cm. We have taken the length of these magnets to be the same as the main ring quadrupoles i.e. 84".

The same plots demonstrate the increasing step size with quadrupole strength. Figure 10 shows a 60% increase over the slow extracted beam spot size. Figure 11 demonstrates how the extracted beam size can be brought back to the slow extraction value of 10 mms by reducing the setpum radial offset to 11 mms (i.e. putting in a fast 3 mm local orbit bump). A surprisingly similar result can also be obtained by leaving the septum radial offset at 14 mm and turning off the extraction octupoles, the results of this approach are shown in figure 12.

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BETA-THETA HMG

$$0.6 \text{ Gev} = 67$$

0.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 226.0893
ALPHA 3.02690

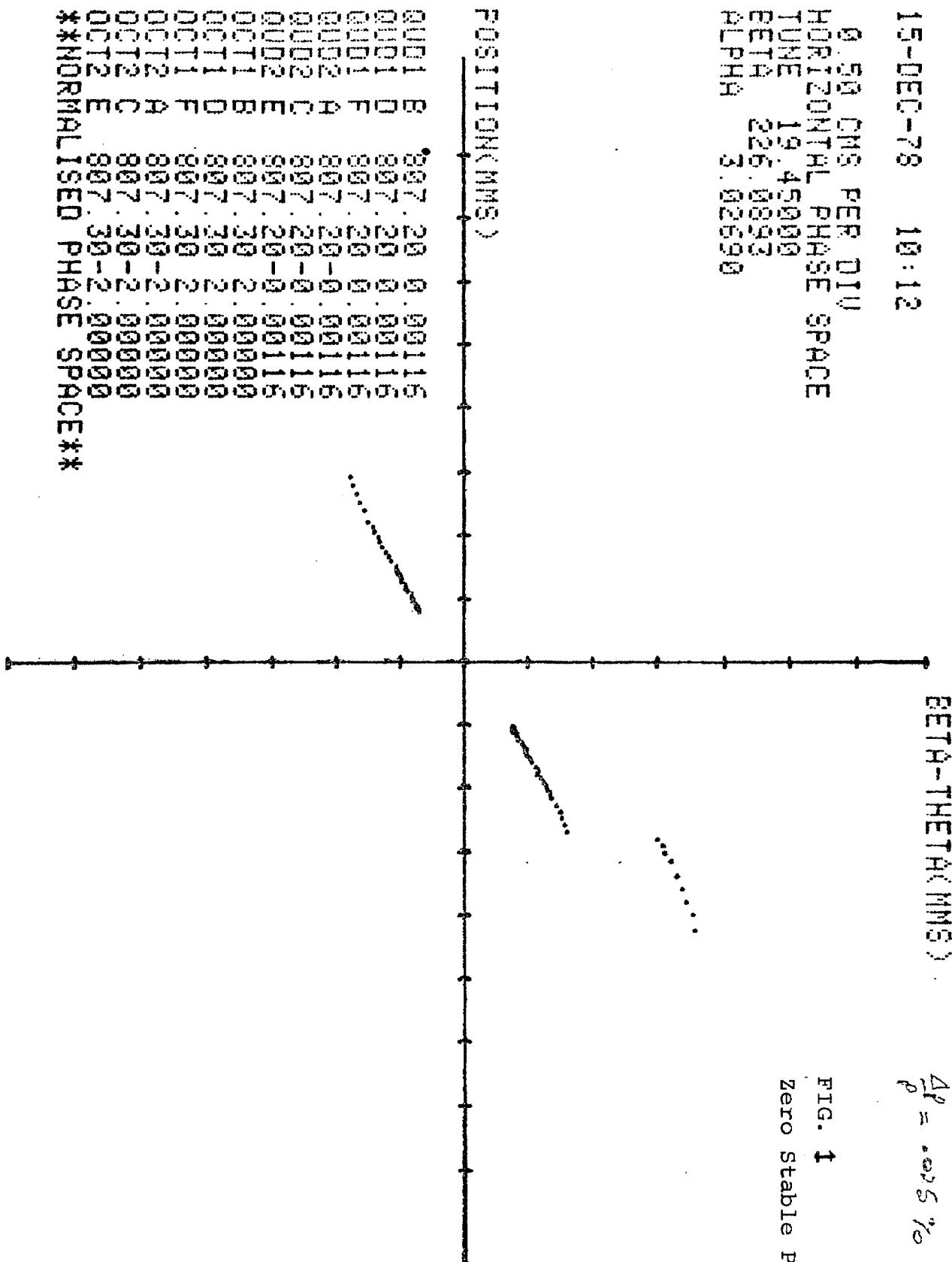


FIG. 1
Zero Stable Phase Space

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BETHA - THE TAKING

$$\frac{\Delta P}{P} = -0.025\%$$

6.50 DHS PER DIU
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 22.4470
ALPHA .63289

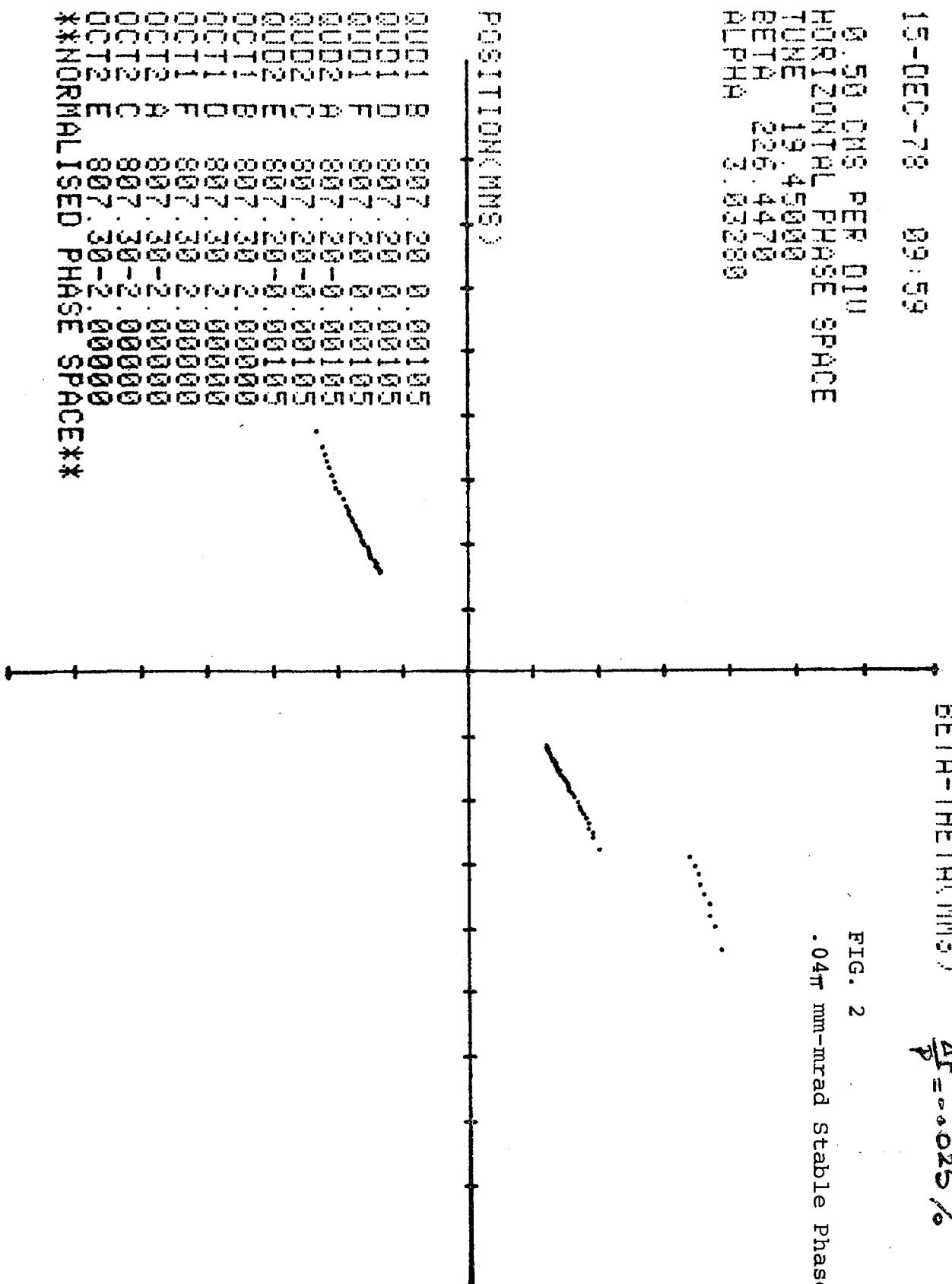


FIG. 2

.04 π mm-mrad Stable Phase Space

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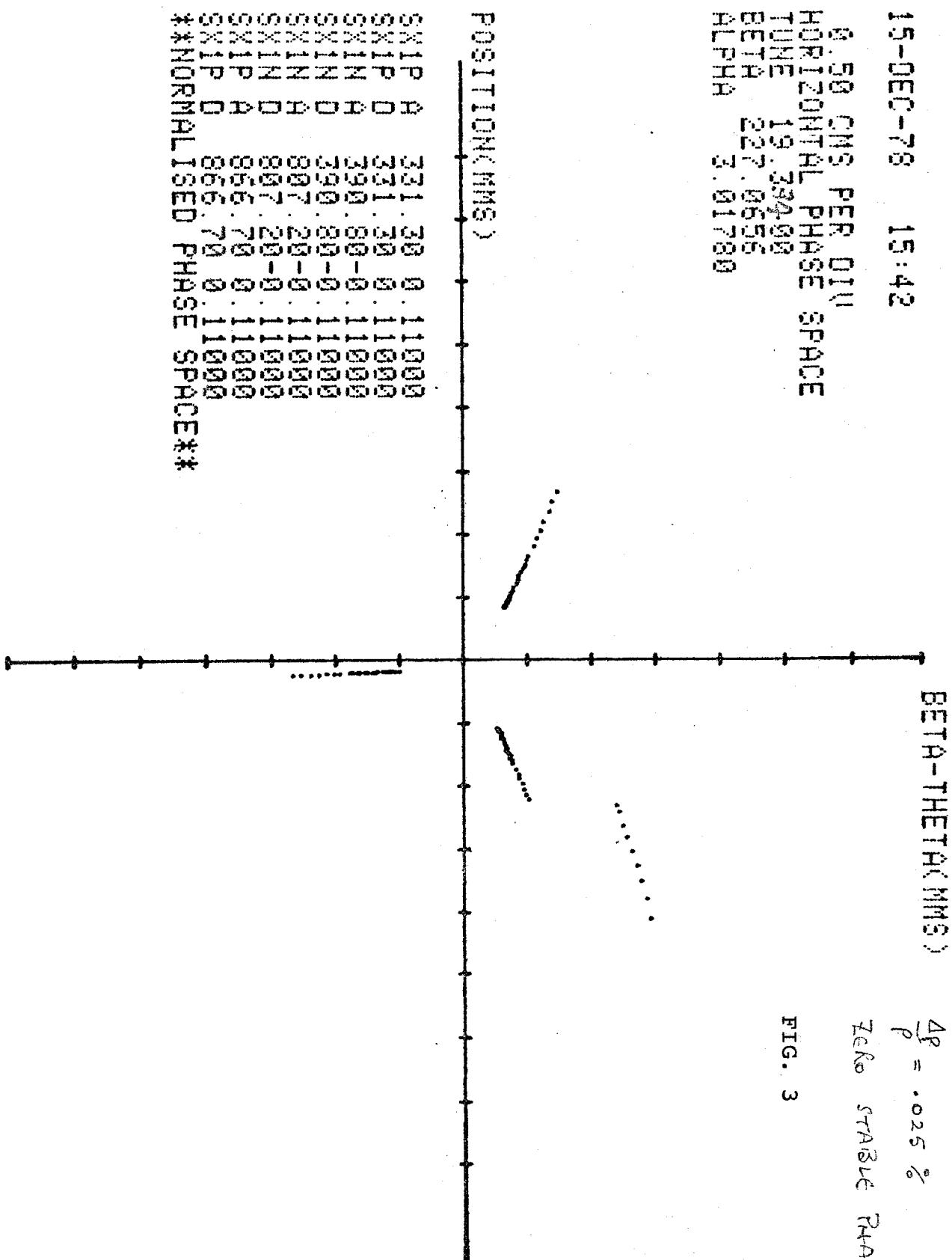
BETA-THETA(KMMS)

$$\frac{\Delta P}{P} = -0.25 \%$$

ZERO STABLE PHASE SPACE

四

6.50 CMS PER DIV
HORIZONTAL PHASE SPACE

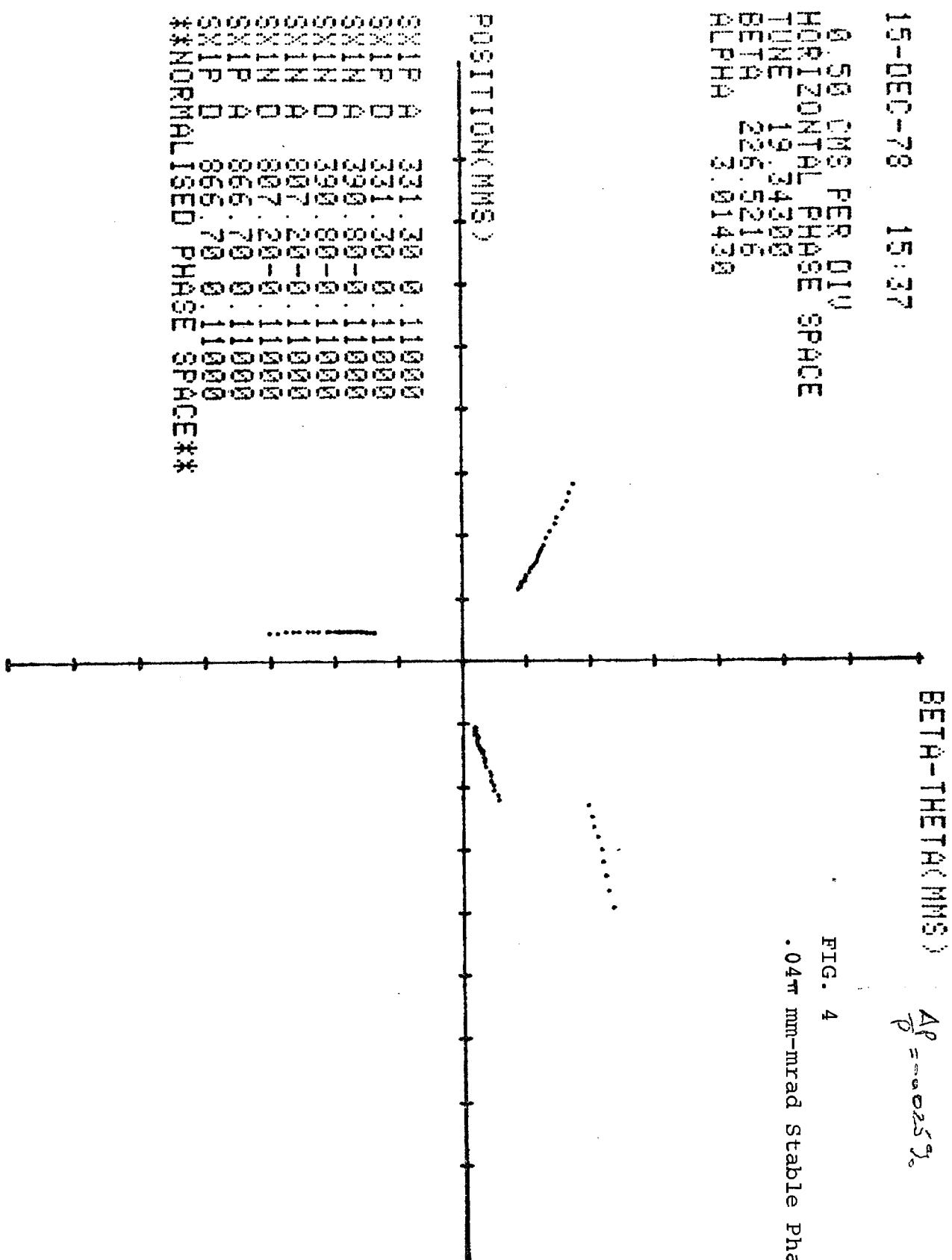


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BETA-THETA(MMS)

$$\frac{\Delta \rho}{\rho} = -0.025\%$$

0.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.34300
BETA 226.5216
ALPHA 3.91438



SYIP A 331.38 0.11000
SYIP D 331.38 0.11000
SYIN H 390.80-0.11000
SYIN D 390.80-0.11000
SYIN H 807.20-0.11000
SYIN D 807.20-0.11000
SYIP A 866.70 0.11000
SYIP D 866.70 0.11000
NORMALISED PHASE SPACE

FIG. 5

Composite of Figs. 1&2

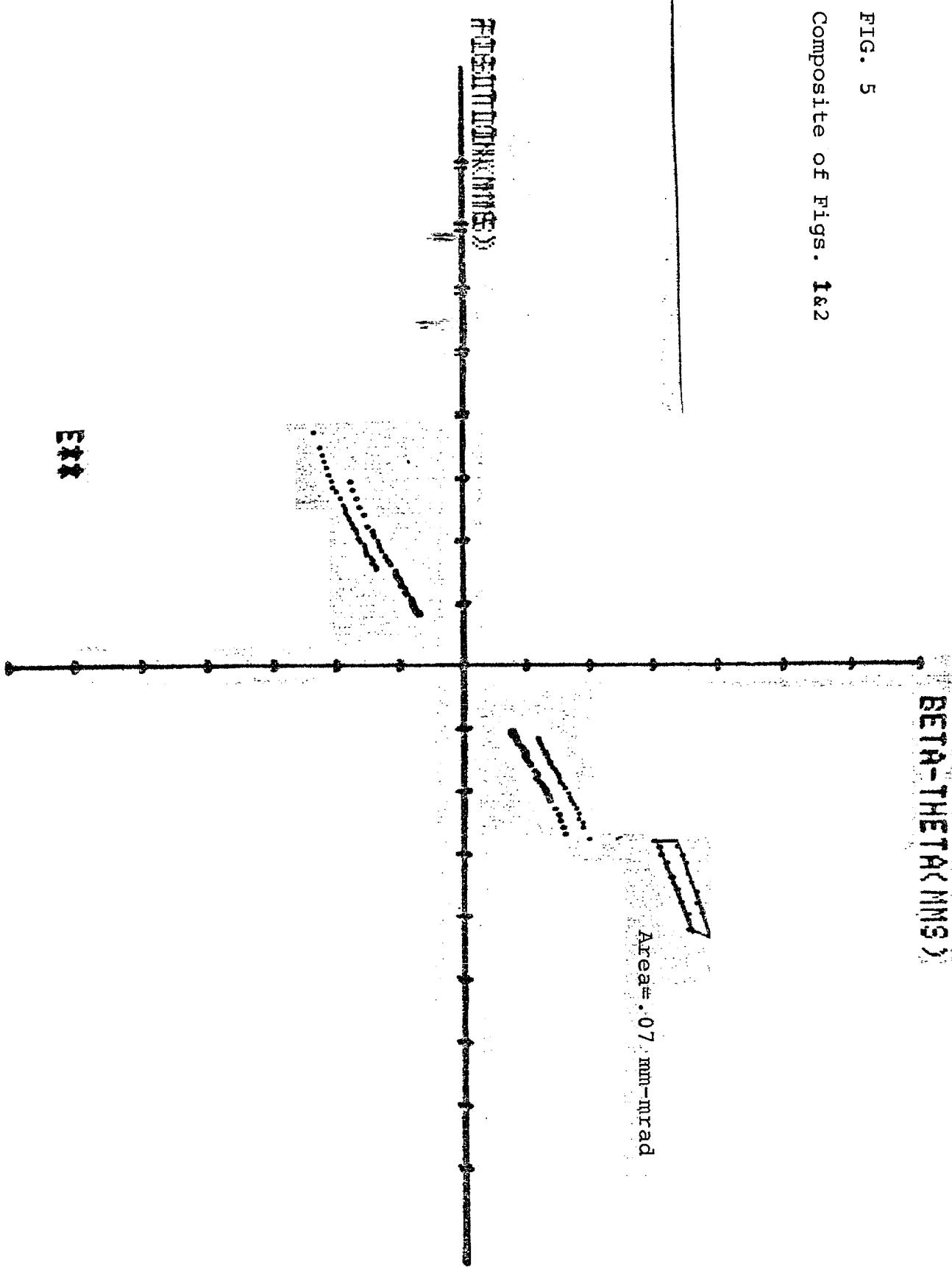
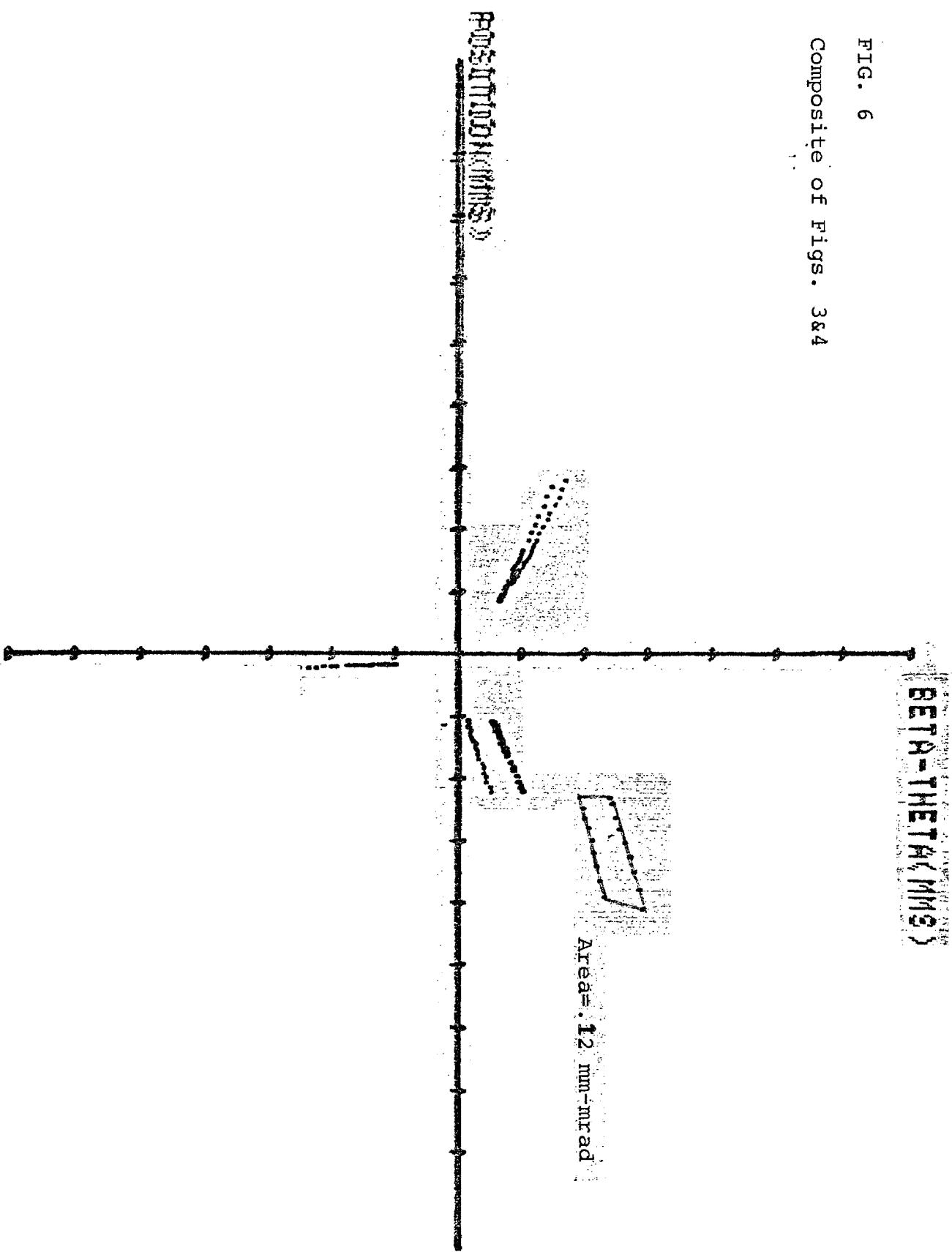


FIG. 6

Composite of Figs. 3&4

BETA-THETA (MM)

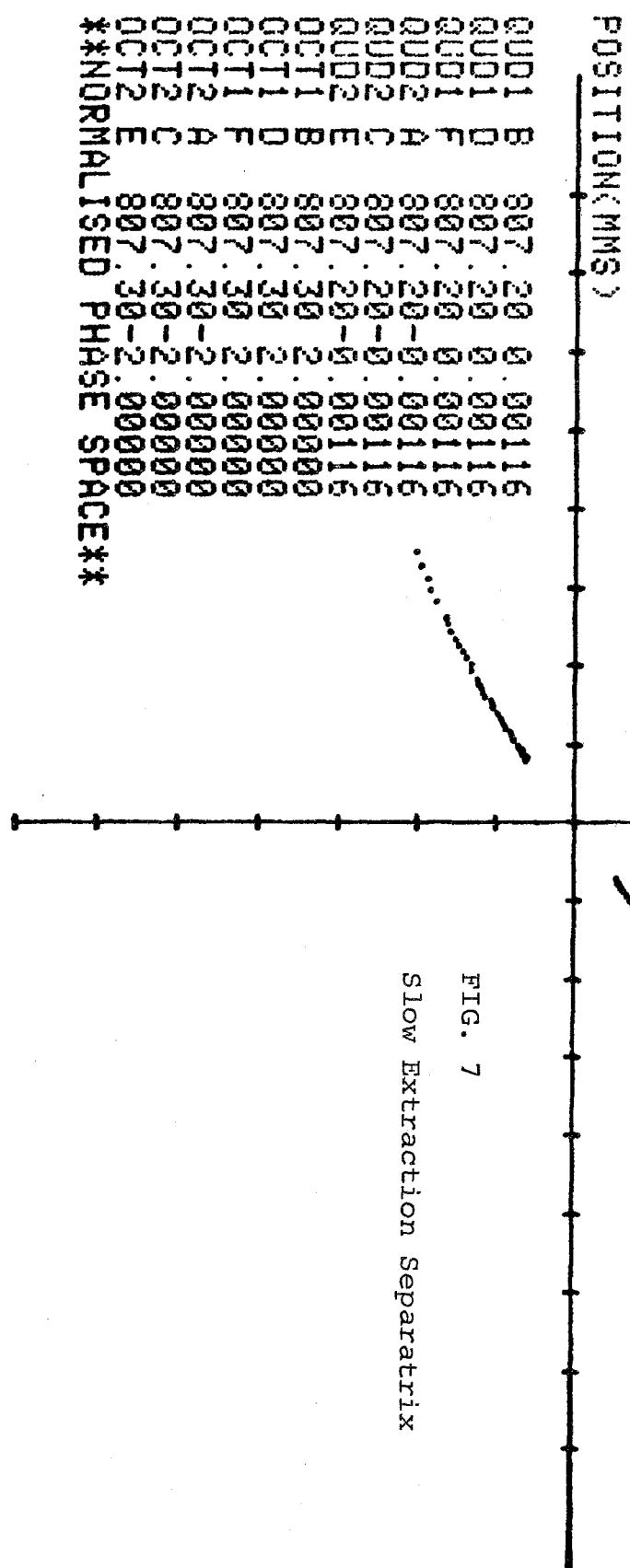
Area = .12 mm-mmrad



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BETA-THETAC(MMS)

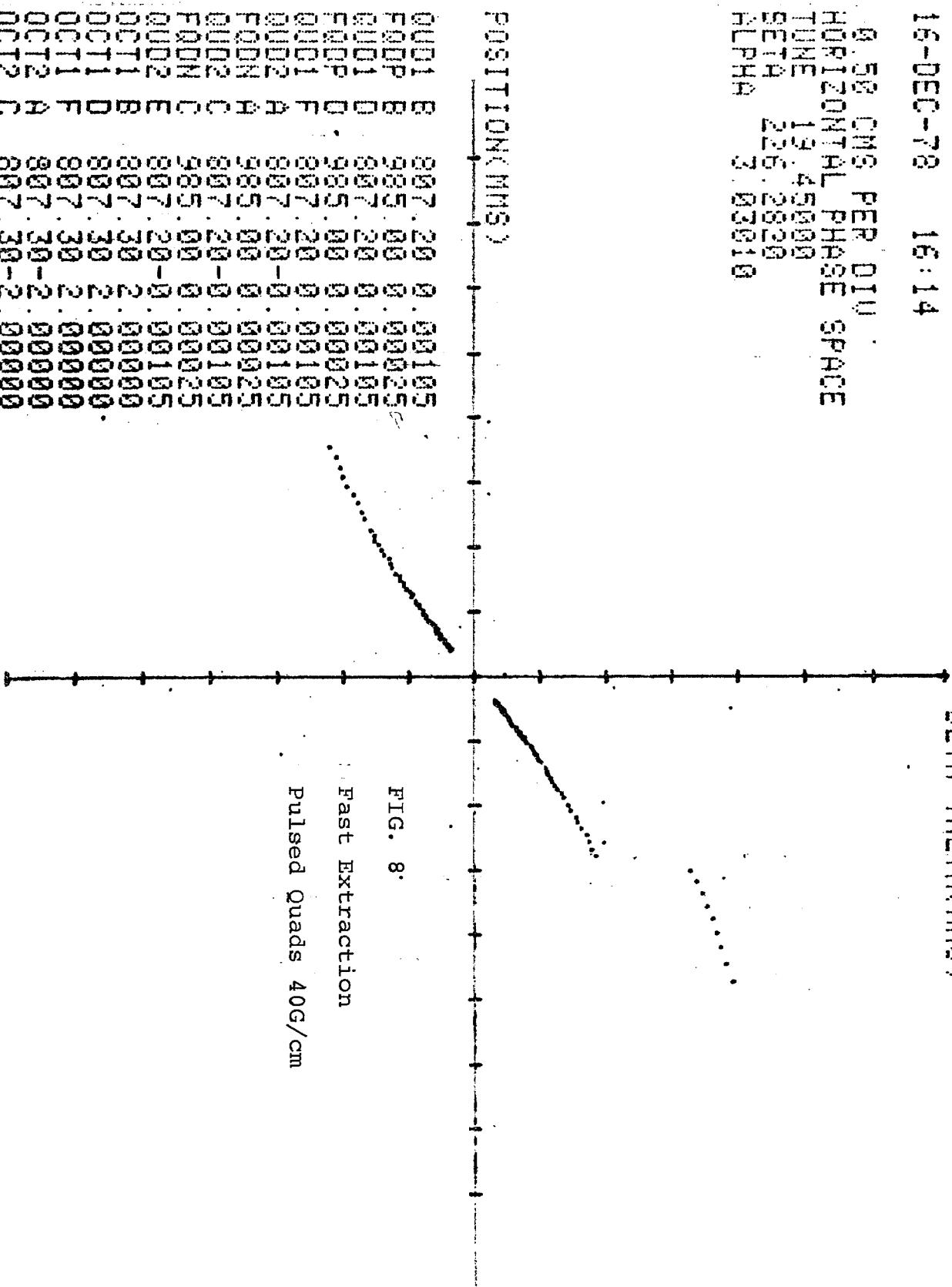
9.58 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 226.2695
ALPHA 3.02990



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BETHÀ-THETÀ (MNG.)

0.58 CMS PER DIV.
HORIZONTAL PHASE SPACE
TUNE 19-450000
SETA 22-120000
ALPHA 3-03610



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16-DEC-78 16:03

BETÀ-THETÀ(MMS)

10.50 CMS PER DIV
HORIZONTAL PHASE SPACE

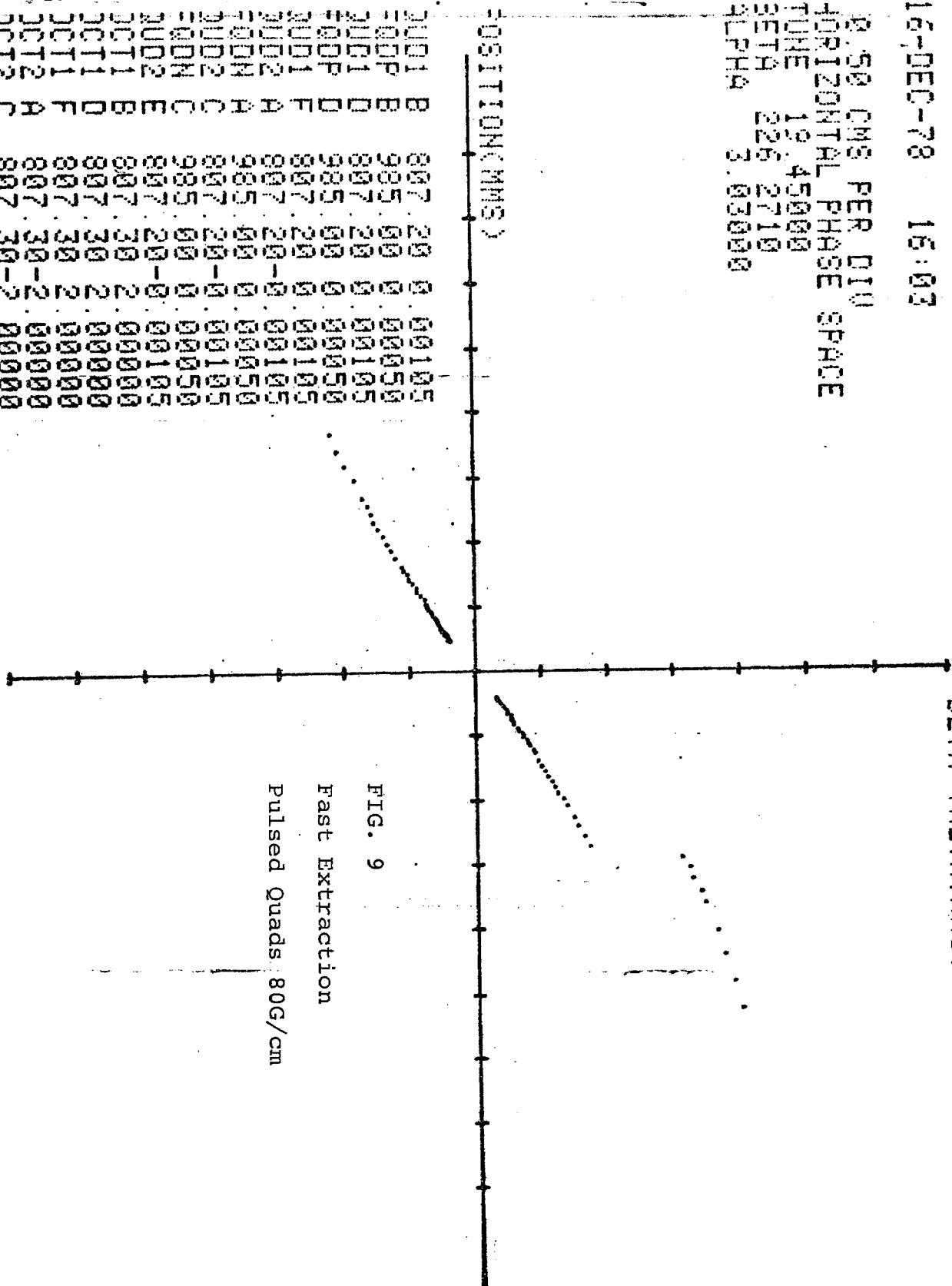


FIG. 9

Fast Extraction

Pulsed Quads: 80G/cm

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BETH-THE-TAKHING

0.50 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45000
BETA 226.2745
ALPHA 3.03000

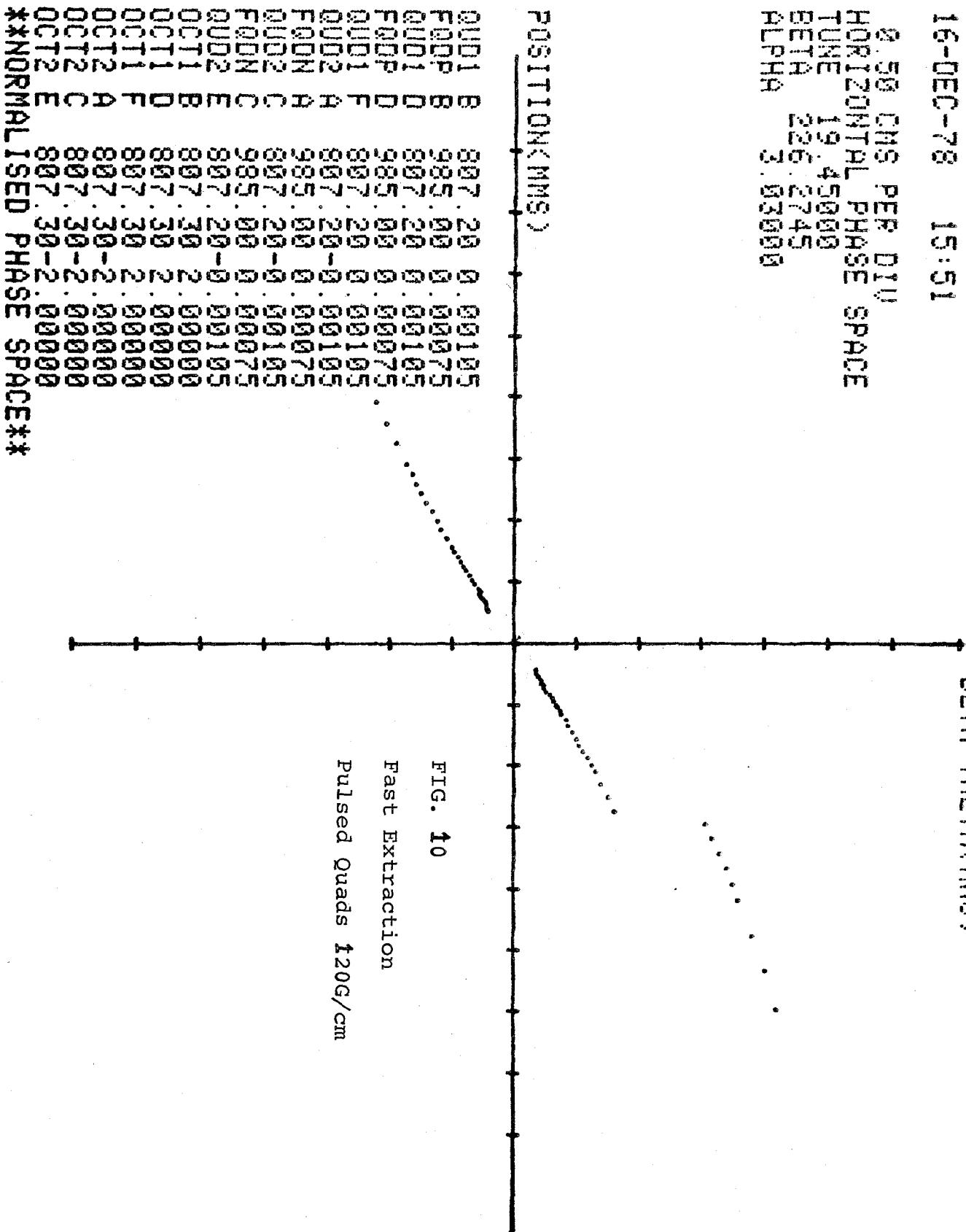


FIG. 10

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BETA-THETA(MHS)

0.52 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNE 19.45030
BETA 226.2745
ALPHA 3.83000

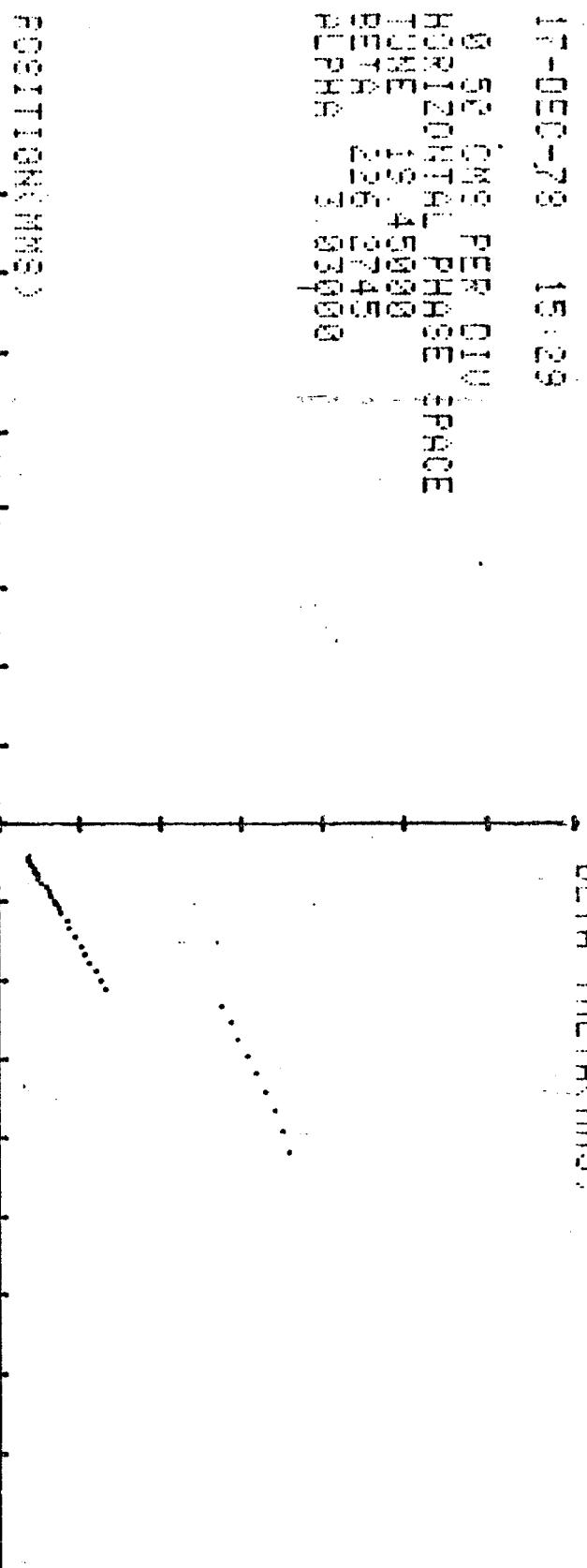


FIG. 11.

Fast Extraction

Pulsed Quads 120G/cm

Septum Offset 11mm

QUD1
QUD2
FUD1
FUD2
FUDN
QUD2
QUDN
OCT1
OCT2
OCT1
OCT2
OCT1
OCT2
OCT2
OCT3
OCT2
OCT3
NORMALISED PHASE SPACE

-24-

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BETÀ-THE THÁC MÌNG

8.58 CMS PER DIV
HORIZONTAL PHASE SPACE
TUNED

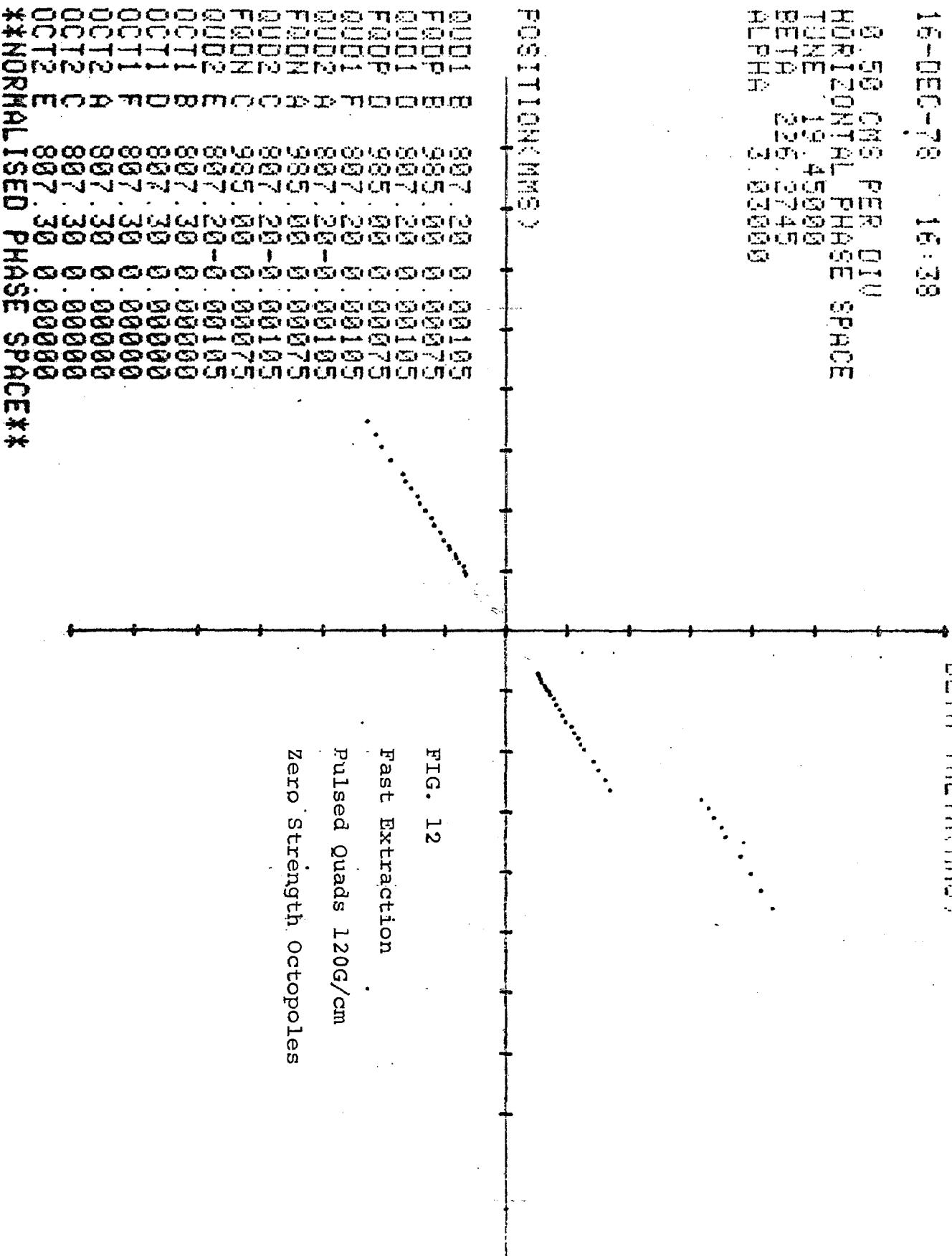


FIG. 12